

FIBROUS SHEET ENHANCEMENT

This application claims the priority of U.S. provisional application Serial No.

5 60/223,251, filed August 4, 2000.

FIELD OF INVENTION

The present invention generally relates to fibrous sheets and more specifically to polymer additives for fibrous sheets.

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BACKGROUND

Fibrous sheets are used for a variety of different purposes and are comprised of an array of different fibers, binders and fillers. For example, fibrous sheets can be used as acoustical ceiling tiles, paper products and furniture board. Primarily, fibrous
15 sheets are comprised of mineral wool, perlite, cellulosic fibers, fillers and binders.

Fibrous sheet production utilizes combinations of fibers, fillers, bulking agents, binders, water, surfactants and other additives mixed into a slurry and processed into a fibrous sheet. Examples of fibers used may include mineral fiber, fiberglass, and cellulosic material. Mineral wool is a lightweight, vitreous, silica-
20 based material spun into a fibrous structure similar to fiberglass. Cellulosic material is typically in the form of newsprint. Added fillers may include expanded perlite, clay, titanium dioxide and calcium carbonate. Expanded perlite reduces material density, and clay enhances fire resistance. Examples of binders used in the

production of fibrous sheets include starch, latex and reconstituted paper products, which link together and create a binding system, locking all ingredients into a structural matrix.

Organic binders, such as starch, are often the primary component providing structural adhesion for the fibrous sheet. Starch is often the preferred organic binder because it is relatively inexpensive. For example, fibrous sheets containing newsprint, mineral wool and perlite are often bound together by starch. Starch imparts both strength and durability to the fibrous sheet structure.

Unfortunately, there is a limit to how much starch can be added before the organic binder's properties begin to decline. Starch is highly water-soluble and, when partially hydrolyzed, loses a portion of its ability to bind the fibrous sheet components. Additionally, water-felted and cast panels tend to exhibit limited stability under high moisture loads given the hydrophilic nature of the cellulosic fibers. Furthermore, fibrous sheet strength and durability cannot simply be enhanced by using increased quantities of starch and cellulose, since starch increases a fibrous sheet's susceptibility to moisture and sag.

Thus, a high degree of starch and cellulose can lead to sagging and weakening of the board. Also, fibrous sheets having large quantities of starch require elevated drying rates to remove excess water from the board. Therefore, there is a need for a method for increasing both the strength and durability of a fibrous sheet without the addition of increased quantities of starch. Additionally, there is a need for a fibrous sheet that is not susceptible to sagging under high moisture loads and does not require increased drying times during processing.

SUMMARY

The present invention encompasses both a method and composition for providing a two-part polymer binder additive for a fibrous sheet for improving both
5 its strength and durability. The two-part polymer binder may be added to augment current organic binders to increase such desirable board properties as strength and durability, or the polymers may be added to reduce the amount of organic binder required. Additionally, the polymers may be added in place of conventional organic binders or added to improve sag resistance in highly moist environments.

10 The two-part polymer binder comprises both the addition of a resin system and an anionic polymer which impart both increased strength and resistance to moisture and sagging. The resin system comprises a polyamidoamine-epihalohydrin resin and a polymer having repeating units derived from an alkyl halide having at least one double bond and an alkene.

15 In greater detail, the two-part polymer binder may be in a ratio of resin system to anionic polymer between about 0.1 to 1 and about 10 to 1 by weight. Additionally, the alkyl halide may comprise an alkyl halide and the alkene may comprise an olefin or an ethylene. Furthermore, the anionic polymer may be a water soluble copolymer.

The method of forming an enhanced fibrous sheet includes the steps of
20 forming a fibrous slurry and mixing into the fibrous slurry a resin system. The resin system comprises a polyamidoamine-epihalohydrin resin and a polymer having repeating units derived from an alkyl halide having at least one double bond and an alkene. Next, added into the mix is an anionic polymer to form a flocculated mix,

which is then formed into a fibrous sheet. The fibrous sheet is then dried to form the finished product.

Furthermore, the ratio of added resin system to anionic polymer may be between about 0.1 to 1 and 10 to 1 by weight. The resin system may be added to the
5 formed fibrous slurry in an amount between about 2 pounds to about 200 pounds per ton of fibrous slurry.

Additionally, a fibrous sheet is provided having at least one type of fiber and an organic binder. The fibrous sheet also contains a resin system having a polyamidoamine-epihalohydrin resin and a polymer having repeating units derived
10 from an alkyl halide having at least one double bond and an alkene. Furthermore, an anionic polymer is also contained within the fibrous sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

15 Figure 1 is a graphical presentation of the plotted indentation data of the control samples as compared to the samples containing the additive polymers of the present invention;

Figure 2 is a graphical presentation of the plotted compressive yield strength data of the control samples as compared to the samples containing the additive
20 polymers of the present invention;

Figure 3 is a graphical presentation of the plotted modulus of rupture (MOR) data of the control samples as compared to the samples containing the additive polymers of the present invention;

Figure 4 is a graphical presentation of the plotted modulus of elasticity (MOE) data of the control samples as compared to the samples containing the additive polymers of the present invention;

Figure 5 is a graphical presentation of the plotted modulus of rupture (MOR) data of a fiber board sample prepared using an inline process run as opposed to a batch process containing the additive polymers of the present invention; and

Figure 6 is a graphical presentation of the plotted modulus of elasticity (MOE) data of a fiber board sample prepared using an inline process run as opposed to a batch process containing the additive polymers of the present invention.

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DETAILED DESCRIPTION

The present invention encompasses both a method and composition for providing a two-part polymer binder additive for a fibrous sheet by improving both its strength and durability. The polymer binder comprises both the addition of a resin system and an anionic polymer which impart both increased strength and resistance to moisture and sagging. The resin system comprises a polyamidoamine-epihalohydrin resin and a polymer having repeating units derived from an alkyl halide having at least one double bond and an alkene.

The resin system is essentially a polyamidoamine-epihalohydrin resin combined with a latex whereby the resin imparts a cationic charge to the resin system. The fibrous slurry is commonly anionic and readily associates with the cationic resin system. The resin system preferably precedes the addition of the anionic polymer.

The anionic polymer is preferably added to the fibrous slurry after the addition of the resin system. The polymer is preferably a polyacrylamide copolymer, such as HERCOBOND 2000[®] available from Hercules Incorporated of Wilmington, Delaware. The addition of the polymer adds a negative charge to the fibrous slurry and aids in the creation of a complex, which imparts both durability and strength to the finished fibrous sheet.

The ratio of resin system to anionic polymer added to the fibrous slurry by weight may be about 2:1. The ratio may be smaller or larger than about 2:1, such as for example 0.1:1 or 10:1 by weight. Additionally, in one embodiment, the resin system is added to the fibrous slurry in an amount between about 2 pounds to about 200 pounds per ton of fibrous slurry. In an additional embodiment, the resin system is added to the fibrous slurry in an amount between about 10 pounds to about 60 pounds per ton of fibrous slurry.

Furthermore, the anionic polymer may be added to the fibrous slurry in an amount between about 0.2 pound to 100 pounds per ton of fibrous slurry. In an additional embodiment, the anionic polymer may be added to the fibrous slurry in an amount between about 1 pound to 8 pounds per ton of fibrous slurry. Of course, even greater amounts may be added to the slurry if the organic binder is to be replaced by or reduced by the added binders. Essentially, the upper limit on the quantity of binder added to the fibrous slurry is limited by economic factors since most organic binders such as starch are relatively inexpensive as compared to the polymer binders of the present invention.

36A The resin system comprises a mixture of a polyamidoamine-epihalohydrin and a component which cooperates with or moderates its properties and may be selected from flexibilizing components. Without wishing to be bound by any one theory, it is believed that the flexibilizing component functions to hinder crosslinking of the polyamidoamine-epihalohydrin. Such a resin system is described in more detail in 5 U.S. Patent Application No. [Attorney Docket No. P19657.S07] and is incorporated by reference as though set forth in full within this application.

In greater detail, the polyamidoamine-epihalohydrin resin may include polyamidoamine-epihalohydrin resins such as those disclosed in U.S. Patents No. 10 2,926,116 and 2,926,154 to KEIM, incorporated by reference in their entirety herein. Polyamidoamine-epihalohydrin resins can also be prepared in accordance with the teachings of U.S. Patent No. 5,614,597 to BOWER, commonly assigned to Hercules Incorporated, which is incorporated by reference in entirety herein. As discussed in U.S. Patent No. 5,614,597 to BOWER, these processes typically involve reacting 15 aqueous polyamidoamine with an excess of epihalohydrin to completely convert amine groups in the polyamidoamine to epihalohydrin adducts. During the reaction, halohydrin groups are added at the secondary amine groups of the polyamidoamine.

After the epihalohydrin has been added and when heat evolution has subsided, the reaction mixture is heated to effect crosslinking and viscosity increase. During 20 this reaction, azetidinium groups are formed. These functional groups are typically employed to impart wet strength to paper by forming a strong crosslinked network with the paper fibers.

Polyamidoamine-epihalohydrin resins for use include polyamidoamine-epichlorohydrins such as those sold by Hercules Incorporated of Wilmington, Delaware, under various trade names. Preferred polyamidoamine-epihalohydrin resins available from Hercules include the KYMENE[®] resins and the HERCOBOND[®] resins; KYMENE 557H[®] resin; KYMENE 557LX[®] resin; KYMENE 557SLX[®] resin; KYMENE 557ULX[®] resin; KYMENE 557ULX2[®] resin; KYMENE 709[®] resin; KYMENE 736[®] resin; and HERCOBOND 5100[®] resin. Of these, KYMENE 557H[®] resin and HERCOBOND 5100[®] may be used as polyamidoamines, available in the form of aqueous solutions. It is expressly contemplated that equivalents to each of the foregoing resins are within the scope of the present invention.

Materials for the flexibilizing component may include copolymers of alkyl halides and alkenes, such as copolymers of vinyl or alkyl halides and alkenes. Any alkyl halide and any alkene, which copolymerize to form copolymers with each other, may be employed. Alkyl halides may include alkyl and/or vinyl halides of from 2-12 C atoms, from 2-6 C atoms, from 2-4 C atoms and about 2 C atoms. Copolymers of vinyl halides (especially vinyl chloride) and alkenes, of from 2-12 C atoms, from 2-6 C atoms, from 2-4 C atoms and of about 2-3 C atoms. Propylene and/or ethylene may be used.

Copolymers of vinyl chloride and ethylene may be employed as the flexibilizing component. Exemplary copolymers of vinyl chloride and ethylene are disclosed in U.S. Patent No. 4,673,702 to IACOVIELLO, and U.S. Patent No. 4,962,141 to IACOVIELLO, et al., incorporated by reference in their entireties herein. These copolymers (also referred to herein as "EVCI" copolymers) may be prepared in

using any known method. By way of example, they may be prepared, for example in the form of an emulsion as described in U.S. Patent No. 4,962,141 to IACOVIELLO, et al.

Suitable EVCl copolymer emulsions may be prepared by copolymerizing the monomers in the presence of suitable emulsifying agents, such as protective colloids and surfactants, in an aqueous medium under pressures generally not exceeding about 100 atm and in the presence of a redox system which is added incrementally. The copolymerization reaction is performed under an ethylene pressure which is sufficient to provide the copolymer with about 5 to 35 wt% ethylene content, preferably about 15 to 25 wt%. Pressures of about 50 to 100 atm are generally used to afford such an ethylene content.

The EVCl copolymer emulsions may additionally contain from 0.1 to 30 weight percent of an external crosslinking agent based upon the total weight of the copolymer. Suitable external crosslinking agents include melamine/formaldehyde resins, polyisocyanates such as water dispersible polymeric methyl diphenyl diisocyanates and water based phenolic resins.

In carrying out the polymerization, substantially all of the polyvinyl alcohol and a portion of the vinyl chloride are initially charged into the polymerization vessel which is then pressured with ethylene. At least about 5 wt% and preferably at least about 15 wt% of the total vinyl chloride to be polymerized is initially charged into the reactor. The remainder of the vinyl chloride is added after the initially charged vinyl chloride monomer content has been substantially reduced. A controlled addition avoids over pressurization of the reactor. No more than 60% of the vinyl chloride

should be charged initially since a prepolymer must be generated in-situ in order to obtain the desired stable emulsions.

The quantity of ethylene entering the copolymer is influenced by pressure, mixing, addition rate and the amount of free radical generating source. The ethylene content of the polymer can be enhanced by increasing the ethylene pressure, increasing agitation and increasing the free radical source rate.

The process of forming EVCl copolymer emulsions may comprise preparing an aqueous solution containing a polyvinyl alcohol dispersing agent. The aqueous solution and initial charge of vinyl chloride may be added to the polymerization vessel, and ethylene pressure may then be applied to the desired value. The mixture is mixed thoroughly to dissolve ethylene in the vinyl chloride and into the water phase. The charge can be conveniently elevated to polymerization temperature during this mixing period. A polymerization temperature of about 55°C and an ethylene pressure in the range of 750 psig to 1000 psig may be employed to provide a copolymer with about 20-30 wt% ethylene. Mixing can be effected by means of an agitator or other known mechanism.

The polymerization is initiated by introducing initial amounts of a free radical generating source into the reactor vessel containing the monomer premix. When employing a redox system, either the oxidant or reductant component can be added initially to the aqueous medium containing the polyvinyl alcohol and vinyl chloride with the other redox component added to initiate the reaction. Upon initiating the polymerization, any desired monomer such as the hydroxyalkyl- or carboxylic acid-

containing functional co-monomers disclosed herein may be added incrementally to the reaction vessel.

The reaction may generally be continued until polymerization is no longer self-sustaining and desirably until the residual vinyl chloride content is below 0.5%.

- 5 The completed reaction product is removed from the presence of ethylene and maintained at a temperature above the T_g of the copolymer while sealed from the atmosphere. The reaction mixture can also be transferred to a degasser for removal of unreacted ethylene.

- 10 One skilled in the art would appreciate that generically or specifically defined reactants and conditions can be substituted by equivalent reactants and conditions. Especially preferred copolymers for the flexibilizing component include those marketed by Air Products and Chemicals, Inc., of Allentown, Pennsylvania, under the trade name AIRFLEX[®]; especially AIRFLEX 4530[®]. It is expressly contemplated that equivalents to such vinyl chloride/ethylene copolymers are within the scope of
- 15 the present invention.

- Other materials for the flexibilizing component include FLEXBOND 325[®] (vinyl acetate-acrylic copolymer latex), LUCIDENE 243[®] (styrene-acrylic polymer emulsion), HYCAR 26256[®] (acrylic ester copolymer latex) and MORKOTE 1725[®] (acrylic copolymer emulsion). Additionally, water compatible systems such as
- 20 copolymers can contain the following monomers: methyl methacrylate, butyl acrylate, styrene, vinylidene chloride, acrylic acid, and methacrylic acid. Suitable copolymers include acrylated urethanes prepared by reacting a hydroxy acrylate or methacrylate; a diol, polyester or diamine; and a diisocyanate can be used. Preferred

monomers are disclosed in U.S. Patent 5,716,603, which is hereby incorporated by reference as though set forth in full herein for its teachings in this regard. Other copolymers that appear to be useful include acrylic and vinyl acrylic-based materials.

The anionic component of the two-part polymer binder additive is an anionic polymer preferably added by weight in the ratio of one-part per two-parts resin system. The polymer can be any linear, branched or crosslinked anionic polymer. The polymer may be a natural or synthetic polymer. For example, the natural polymer may be carboxymethylcellulose (CMC), and the synthetic polymer may be a polymer or copolymer of acrylic acid.

The anionic polymer is preferably water soluble and, by way of example, may be comprised of an acrylamide or acrylic polymer or combinations thereof. The molecular weight of the anionic polymer is not critical, but is preferred to be within a range of up to about 1 million. Of course, the molecular weight can be greater than the preferred range which is contemplated for use within the present two-part polymer system. Polymers having a very low molecular weight are essentially limited only by economics, since more polymer must be added to give a desired result.

In an embodiment, the anionic polymer may be a water soluble acrylamide terpolymer described in U.S. Patent No. 5,543,446 and incorporated by reference as though set forth in full within this application. The terpolymer comprises a (meth)acrylamide, an ethylenically saturated, aliphatic carboxylic acid or salt and a water-soluble polyvinyl monomer. An example of such a terpolymer can be acrylamide/acrylic acid/methylene-bis-acrylamide having a molar ratio of about 92/8/0.018. As can be seen from this example, the water-soluble polyvinyl monomer

component of the terpolymer comprises only a fraction of the terpolymer's total composition, thus copolymers of acrylamide and acrylic acid may also be used.

While not being bound to any one theory, it is believed that the two-part polymer binder forms a complex, which is crosslinked and forms a lattice work around the negatively charged fibers of the slurry sheet forming the board. The resin system is cationic, and the anionic polymer is anionic. The resin system may be added first to the fibrous slurry since the slurry or fibrous component is negatively charged and is attracted to the positively charged resin system. The anionic polymer is preferably added after the resin system as the negative charged dry binder can then bind and crosslink with the positively charged resin system to form a complex.

Examples

The invention will be more easily understood by referring to the examples of the invention and the control examples that follow. The following examples are given for illustrative purposes and are not to be understood as limiting the present invention.

The modulus of rupture (MOR) of the board is measured by the procedure given in ASTM D-1037. MOR is calculated as being equal to $3PL/2bd^2$ psi where:

P = peak force required to break the samples (lbs.)

L = span between the sample supports (inches)

b = width of the sample (inches)

d = thickness of the sample (inches)

MOR is corrected for density variations by multiplying by D^2 where $D = \text{desired density/actual density}$, wherein the desired density is 1.40.

The modulus of elasticity (MOE) is essentially the measure of flexibility and can be determined using the equation below:

$$MOE = \left(\frac{1}{4}\right) \cdot \left(\frac{L}{t}\right)^3 \cdot \left(\frac{1}{w}\right) \cdot \left(\frac{F}{d}\right)$$

where:

MOE = Modulus of elasticity in flexure, [psi]

L = Length of test span, [in]

t = Thickness of the sample, [in]

w = Width of the sample, [in]

$\left(\frac{F}{d}\right)$ = Slope of the force - deflection curve recorded by the Instron, [lbf / in]

The density of the board products set forth in the following examples is expressed in pounds per board foot (pfd) and is determined by weighing a sample board having dimensions of one-foot square and a thickness of one inch. The density calculation for thinner or thicker boards is computed by dividing the weight of a one-foot square board sample by the thickness of the board sample expressed in inches.

The resin system component, known herein as Example A, can be prepared by adding 42.2 dry grams of KYMENE 557H wet strength resin available from Hercules Incorporated of Wilmington, Delaware, to 25 dry grams of Airflex 4530 available from Air Products and Chemicals, Inc. of Allentown, Pennsylvania, with mechanical stirring. Next is added 62.5 grams of demineralized water to the mixture to yield a slightly blue opaque white dispersion that is then stirred for about 15 minutes at room temperature.

The resin system component, known herein as Example B, can be prepared by adding 100 grams of Hercon[®] 70 sizing emulsion available from Hercules Incorporated of Wilmington, Delaware, to 100 grams of Example A to yield an

about 1-3 minutes. After the addition of the resin system component, Hercobond 2000[®] was added and mixed for about 1-3 minutes. A retention aid, Hercules 8102E, was also added and mixed for about 1-3 minutes after the addition of the Hercobond 2000[®].

- 5 The formed fibrous mix of raw materials and component polymers was formed and pressed into a fibrous sheet of about 14 inches wide by 26 inches in length. The fibrous sheet was first drained for about 25 seconds and vacuum treated after about 15 seconds to a thickness of about $\frac{3}{4}$ inch. The sheet was then further pressed to a thickness of about $\frac{1}{2}$ inch on a porous plate with pressing conditions
- 10 pressed to stops of greater than 7 tons and gauge pressure of 30 seconds. The sheet was then wrapped in foil and dried for about 1.25 hours at 375°F and then unwrapped and dried for about 2.25 hours at 375°F. The sheets were wrapped in foil to aid in the gelling of the starch under test conditions. Foil sheets are not required under typical production runs in an operational plant. The density of the finished handsheets ranged
- 15 from between about 1.15 to about 1.25 pounds per board foot.

TABLE 2

Sample	MOR (psi)	MOE (ksi)
Control 1	168.9	27.47
Control 2	173.4	28.33
1	189.0	31.36
2	189.0	32.88
3	204.3	33.71
4	208.0	34.13
5	195.8	35.35
6	185.6	30.85
7	180.8	30.94
8	187.9	31.38
9	188.3	31.90
10	190.3	33.94

Table 2 illustrates the modulus of elasticity (MOE) and the modulus of rupture (MOR) of the test sample handsheets, plus two control sheets formed from the same components, except for the additive polymers of the present application. Table 2 highlights that the handsheets formed with the additive polymers of the present application have improved MOE and MOR qualities as opposed to the control sheets formed without the additives.

TABLE 3

Experiment	Amount of Additive (%)			Dry Tensile (lb/in)	Wet Tensile (lb/in)	Wet Tensile/ Dry Tensile (%)
	Kymene 557H	Example A	Hercobond 2000			
1 (Control)	0	0	0	25.6	0.7	3
2	0.5	0	0	27.8	6.9	25
3	1.0	0	0	29.5	8.5	29
4	0	1.0	0	30.4	7.5	25
5	1.0	0	0.5	31.3	10.0	32
6	0	1.0	0.5	29.4	7.8	27
7 (Control)	0	0	0	19.4	0.4	2
8	0.5	0	0	22.2	4.2	19
9	1.0	0	0	23.5	4.3	18
10	0	1.0	0	24.1	4.8	20
11	1.0	0	0.5	25.4	5.4	21
12	0	1.0	0.5	24.5	4.8	20
13	0	3	1.5	48	12.0	25.0
14	0	6	3.0	60.0	16.5	27.5
15	0	6	1.0	50.0	10.5	21.0

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Illustrated above in Table 3 are the experimental test results for various cellulosic sheets of paper. The sample sheets were prepared by introducing one or more of the following polymer components: Example A, KYMENE[®] 557H and HERCOBOND[®] 2000 into the pulp mix. Additionally, two control samples were produced which did not include the addition of the above polymer components.

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Samples 1 through 6 were prepared using a mixture of Townsend Paper unbleached kraft pulp and Stone Container double-lined kraft pulp (which was washed after repulping) in a ratio of about 3 to 1, respectively. Samples 7-12 were prepared using a mixture in a ratio of about 1 to 1 of Georgia Pacific St. Croix Northern Hardwood and Georgianier J Softwood pulp.

The paper samples were prepared on the JACKSONVILLE PAPER MACHINE (a pilot paper machine) and refined to 408 cc CSF ("Canadian Standard Freeness") for sample sheets 1-6 and 485 cc CSF for sample sheets 7-12. The dilution water had 25 pm alkalinity (NaHCO_3) and 50 pm hardness (CaCl_2).

10 The test samples were either prepared with Example A or KYMENE[®] 557H. Additionally, HERCOBOND[®] 2000 was added to both the Example A and KYMENE[®] 557H containing samples. The test data illustrates that the two-part polymer formulation can be used to impart wet and dry strength to paper. For example, the test data indicates that Example A, which is about 63% KYMENE[®] 15 557H and 37% Airflex 4530, provides good wet strength, as measured by the ratio of wet tensile to dry tensile in experiments 4 and 10 when compared with experiments 2, 3, 8 and 9. Additionally, when HERCOBOND[®] 2000 is added, both wet and dry strength are improved as illustrated in experiments 5, 6, 11 and 12.

While Applicants have set forth embodiments as illustrated and described 20 above, it is recognized that variations may be made with respect to disclosed embodiments. Therefore, while the invention has been disclosed in various forms only, it will be obvious to those skilled in the art that many additions, deletions and modifications can be made without departing from the spirit and scope of this

invention, and no undue limits should be imposed except as set forth in the following claims.

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